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# ACCOMPLISHING USEFUL DEVICE FUNCTIONS WITH ROLAMITE

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## INTRODUCTION

Using models of actual rolamite devices, rolamite inventor Donald F. Wilkes conducted a tutorial demonstration of rolamite properties, emphasizing those characteristics which lead to applications. He defines the rolamite design as a superior suspension system with inherent low friction, low energy loss, ease of manufacture, and great design versatility.

The text which follows is taken directly from Wilkes' explanations of how the characteristics being demonstrated can lead to rolamite applications.

## ROLAMITE DEVELOPMENT HISTORY

When I was at Sandia Laboratories, the microminiaturization program started in 1962 and took a good deal of effort over a 4- or 5-year span. The modular family of miniature devices that evolved were small in size, about 1/40th of a cubic inch in volume. At the conclusion of the program, we started trying to do a better job in the suspension system, and one of the things of interest was the flat-edge suspension (see Figure 1).

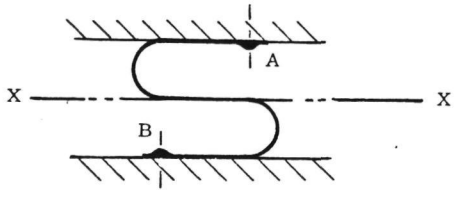


Figure 1. S-Shaped Elastic Suspension

It is very free and a little bit wobbly, not too stable. If you grab hold of it somewhere and roll very far, you will wind up being in one of the lobe areas. The idea occurred to me that if you were to put rollers into the flat-edge suspension you would be able to stabilize this, which is, of course, the origin of rolamite itself. You can see it is a pretty free suspension and it works equally well on the side, upside down, anything you can think of adds a little more realism to it.

Basically, the rolamite is an extremely adaptable, low-friction, suspension system, capable of simultaneously providing (usually with a lot fewer additional parts and a lot less complexity) all of the ingredients needed to build most kinds of mechanisms and mechanical devices. By suspension system I mean that part of a machine that makes the separate moving parts within it behave in a certain way with respect to each other and with respect to ground. So it is really the part of the mechanism that determines the character of the mechanism.

## CONVENTIONAL BEARING PROPERTIES

In the broadest sense, a suspension system constrains the parts to behave in the right way. Let me first demonstrate some of these basic characteristics by making comparisons. I am going to use a roller bearing for some comparisons. Now do not misunderstand; I am not saying that I think the rolamite is primarily a bearing, or that it can be compared directly with a roller bearing. I am using this as a way of trying to bring out a different insight into the rolamite itself. First of all, with a roller bearing, you have an inner and an outer race structure, and then you have a lot of cylindrical rollers arrayed between and around the race structure. By definition, these rollers have to be almost identical in diameter or, if you permit them to roll ahead, they will interfere and slide. So a great deal of precision is required to manufacture a bearing or roller bearing or any other kind of a bearing in order to get the rolling elements to cooperate and not dissipate energy by sliding. You usually have to select the diameters, in order to get a successful, cooperating group.

Also, we have the fact that a separator is generally needed. If we took a full complement, an annular region that was completely filled with rollers, unless they were absolutely perfect, and they rolled any distance at all, one would end up pushing against the other and we would be dissipating energy at twice the rate of the forward motion of the rollers because we have one moving down and the other moving up. In order to get around this problem, separators are normally resorted to, which neatly cut the friction in half. But, of course, their mere presence almost makes a lubricant mandatory because you do have sliding going on at very high rates between the rolling elements and the separator.

Another thing that is needed in this kind of bearing is fairly high pressure, because, even though we select the rollers as well as we can to be exactly the same, there are still imperfections and they are not exactly the same diameter. So a rather high force is needed which implies high pressures in the contact areas in order to mash out the irregularities, to mash out the differences between the cylinders and get them to cooperate.

This bearing also has within it an inherent tendency to align itself. The rollers in the bearing want to align themselves with the axis of the inner race and the outer race because the outer race structure is concave and sort of like a ping-pong ball in a dish; if you will give it time, it will settle to the bottom.

In summary, because of the concavity of the outer race, there is a slight tendency for the roller to retain a certain position when it isn't very strong at all. And, because of this, in order to be able to carry any side load at all, the separators are resorted to for additional alignment. Likewise, the rollers themselves must be maintained within certain proportions or they will not be able to bear the side loads well. If they get too long, then they will tip over and continually dig into the surfaces that are needed to hold them in line to keep them running straight and true. As a consequence, we have built-in sources of sliding within this kind of bearing, a definite need for lubrication all the time, and an extremely vulnerable situation as far as wear is concerned.

Any kind of real, live loading situation ends up being somewhat asymmetrical. And so you have a guaranteed source that the separators which are being relied upon for alignment are going to wear asymmetrically and you are going to accentuate the problem with time. Then you are stuck with certain kinds of proportions on the rolling elements just to get them to behave themselves at all. In a bearing like a needle bearing, we find that the rollers are very ill-behaved and in fact, for the average needle bearing, the rolling elements spend their full life at something between 10 and 15 degrees askew with the rolling axis. And energy is being dissipated and the things are wearing out all the time. I am not saying that they are not adequate, but they are not very elegant. Then these kinds of sources of rubbing make the bearings undesirable for precision applications like a head stock in a precision lathe. They are sources of noise and wear which keep these things from running as truly as they might.

## ROLAMITE BEARING PROPERTIES

In contrast, with rolamite we have a situation where the rolling process is independent of the roller size, so the size of the rollers does not make any difference and is not going to influence the rolling process. We have had as much as a 300-to-1 difference in diameters and we still get a very good rolling behavior. To do this, we have to have a band that is compatible with the smallest roller; we do not have a situation where the roller diameters have to be selected as any particular diameter in order to roll.

Also, we are guaranteed nonslipping behavior, independent of diameter, by a physical law, which is the law of flexure. When I take a flat, elastic member and bend it, the inner fibers have to shorten automatically to exactly the radius that they occupy in space. And this is the requirement that gives us a nonslipping geometry. The band in a rolamite separates the rollers, but it is a much different beast than a separator in a roller bearing. One of the functions of the band is that it forces; if you can look at the band (Figure 2) and the way it pulls, on, let's say, the metal roller A, you will notice that the forces force this roller into the "v" that is formed between the guide surface and the other roller B, and then in reverse just the opposite is happening on the other roller, so you have a geometry that uses the well-known alignment principle of a "v" guide to align a cylindrical object, and it is a very strong force; in fact, for comparable diameters and lengths of rollers as compared with our original roller bearing we have a difference in this alignment tendency of the order of 1000 to 1.

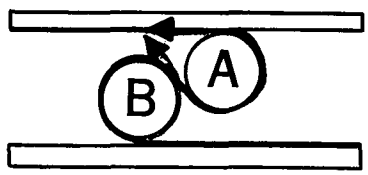


Figure 2.

Now we have a relative minimum but, instead of a shallow dish, we have a very steep energy well and a very strong, aggressive tendency to hold and retain this truly aligned condition. This is an important difference with the rolamite, and, really, is the reason it works well. Do not be misled; if you do a poor job of making the surfaces parallel, or if the surfaces are askew sideways, you have a built-in source that is going to try to tear the suspension apart, so what I say only pertains if the thing is done properly.

We also have provided by the band a traction which keeps these rolling elements from slipping, and it is because of this that the repeatability, after a great number of traverses, is possible. We have a combination of the tensile force and the normal reactive forces occurring to hold these elements in place in the band.

Then we have one other valuable feature coming about because of the band, and this is compliancy. We have two important sources. One is the tensile compliance of the band itself. Here we are comparing a long, relatively low-spring-constant material of the band with a squat object like the roller, which is in both compressions. If you try to roll over a little ramp or particle, the band can accommodate that by merely stretching. I am not talking about strength now; I am just talking about the rate at which force changes with the flexion. Then the second source, in nearly all rolamites that I am concerned with, anyway, is that the tensions we are employing are not so great but that we have some small degree of compliance at the tangent zones. In other words, there is some looseness here which provides a very good functional compliance in making these things work in spite of imperfections that the manufacturing process might introduce (such as lobes or surface roughness).

Another thing that I think is very important in the comparison is the degree of perfection in the rolling process; with the rolamite the process is so much improved that now the need of a lubricant often vanishes. You do not have to have any lubricant at all, or if you do need it, you

are not critically dependent on it. The rolamite can operate for fairly long periods of time, even in a situation where it does need lubrication, without actually degrading too badly. In a roller bearing, because you have to lubricate it, you have energy dissipated by merely pumping the grease or the oil around inside the structure. It is ironical that that energy loss has nothing to do with the prime rolling function. In your car, for instance, there is the case of tapered roller bearings rather than straight roller bearings, but you are paying several cents a mile just to pump the grease around in your front wheel bearings. Because of the lower energy loss, we have less wear, less noise, and less heat, and this sometimes means that you can operate at a higher speed, for instance, because heat is often a dominant factor.

I think the biggest difference occurs in the bearing pressures that are needed to make the bearings behave themselves. There is not a rolling bearing of any kind being used according to the manufacturer's specifications that is not loaded to at least 100,000 psi in the contact zone. The contrast is that the rolamite operates very well, gives you very good behavior, down into the domain of as low as 300 psi--something that I have tested which works very well. I am not saying that that is the absolute lower limit, but at least at that limit it is still working well. This is where the biggest difference occurs. If you are trying to support very heavy loads, this is an insignificant fact; we are not talking about these kinds of pressures. It makes the biggest difference in the field of instruments, because if you are trying to use small ball bearings in an instrument application, you have to load it up to where you have that kind of pressure in the bearing zones just to get it to work. A rolamite device can be built to operate very sensitively with much lower pressures.

The alignment tendency does one other thing for you in the rolamite. It makes it possible for you to take side loads and carry them very well, and to be independent of the proportions of the roller. In rolamite, the wider the bearing the better the alignment tendency of a roller. In the roller bearing, if you are going to have any side load at all, you dare not get the rollers longer than two or three diameters, or they will be unstable. And they are always trying to climb up over the surfaces that hold them in on the end. In the rolamite the alignment is so much stronger that you can very effectively carry side loads with these things. The other fact that has changed markedly is that you can make these bearings as wide as you want to; to carry the load you no longer have to stick to proportions like those in the other kinds of rolling bearing.

In addition, there are two parameters that we can adjust: the tension of the band and the angle of repose. With a fairly low angle of repose the cluster can get over obstacles by merely lifting, decreasing the angle of repose a little bit, and the band can accommodate this. On the contrary, if you go to a very high angle of repose, the cluster becomes friction-locked against side loads or any kind of a change, and actually the band no longer sees any large load, so by this scheme it is possible to take a very thin band and support a very big load with it. It is much harsher, and if you will remember the force relationship, the normal force was equal to the band tension, times the guide surface spacing, divided by the horizontal distance between the center lines. In other words, the normal force N was equal to TS divided by A. You can see that this term S over A is a measure of the angle of repose. As A approaches S, this approaches 1, that is the case where the rollers would be full-sized in the channel, and in this case you have the most compliant geometry of all.

If, on the other hand, you let A go to zero (in other words, you let these things come to where they are almost ready to pass), then you can see that this term can approach infinity, and so for a very light tension you can get a very high normal force. This makes it possible to have great design flexibility; you can make them as wide as you please, you can make them as stern as you please, you can carry any kind of side load you want, because when you go to a high angle of repose, the behavior is very similiar to the load-carrying capability of the roller bearing.



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## ROLAMITE FRICTION AND LOADING

The coefficient of friction is defined as the frictional force measured at one or the other roller centerlines and divided by the normal force; i.e., N is equal to TS over A. Then you can derive that the frictional force is actually going to be just TS over A, times the coefficient of friction, and you see that the friction is then a function of the band tension and the angle of repose times the coefficient of friction. What is meant by "one or the other roller centerlines" is that the rolamite is a case in which you have complete reciprocity; a force that is measured on one of these rollers will be measured exactly the same on the other roller centerline even though the rollers are of different diameters, even greatly different diameters. This is true to a first approximation and it is quite literally true in a tight geometry, so that is what is meant by the frictional force, and we always refer it for ease to the centerline. With the values that we have got, 0.0003 is about the smallest that I have ever seen repeatedly on 1/2-inch-diameter rollers 3/4 inch long. This is sort of standardized to give us something to gather data on that would have some meaning. The very worst that I have ever seen on this size roller is 0.0015, and the average value of all the tests on all materials on the 1/2-inch diameter will be 0.0008. This figure pertains to two-roller clusters; if you add more rollers you have to add more. If you took a four-roller cluster it would be reasonable to double this number. The primary difference, though, comes about in the bearing pressures involved, so the biggest difference between rolamite and conventional bearings comes about in the low pressures required. For instrument and light usage, you are able to use these extremely low coefficients of friction down into pressures as low as 300 psi instead of up in the zone of 100,000 psi, and this is a big difference. Under comparable loads the friction between the rolamite and a regular bearing begin to come together. The residual sources of friction in a regular bearing do not continue to mount with increasing load. So if you load the rolamite heavily enough with a comparable number and size of rolling elements, it would compare very favorably, with possibly a little bit less friction, to a regular rolling bearing, but certainly not be very much different.

## SUMMARY OF ROLAMITE PROPERTIES

I have been talking about the suspension aspects of rolamite, and there are three things that are particularly important here. First, we have a very low friction system. Second, we have a system which is compliant and tolerant of imperfections, and variation and contaminations. Third, it is also very adaptable to a wide range of uses. Consider a four-roller cluster. Notice that you can have all different diameters as long as two adjacent rollers meet the constraint that they do not pass each other and still roll. The reason you might want to do this is that it makes it possible to spread out load, distribute load; it makes it possible for you to have immediately available, in coupled form, many different rotational velocities at the same time. The rotary geometries have already been talked about so I will just show you another kind of multiroller situation. This appears to be very nearly the same thing just discussed; the only difference is that it is actually two separate clusters. This brings out another important feature: the rolamite can have as many separate clusters operating in guide channels as you want. These clusters do not have to have two rollers; they can have as many rollers as desired, as long as they are in multiples of two. This is particularly useful, because one cluster can work on the other without any sliding at all, or they can operate independently, anywhere in their travel. One way in which this becomes particularly useful is in breakaway devices; one of these clusters can break away when some particular force level is seen, the other one then can be allowed to come down without any biasing forces of any kind as restrained by a viscous force or some other kind of force.

## FORCE GENERATION

By employing a band with a rectangular cutout in it, we can produce a constant force over a limited zone (see Figure 3, Constant Force). If we roll out of the zone where the cutout is exerting an influence, we are back in a neutral geometry again where there is no force. Next consider a spring constant, the same kind of action you get from a screen-door spring if you extend it. Figure 3, Negative Spring Constant, shows this case.

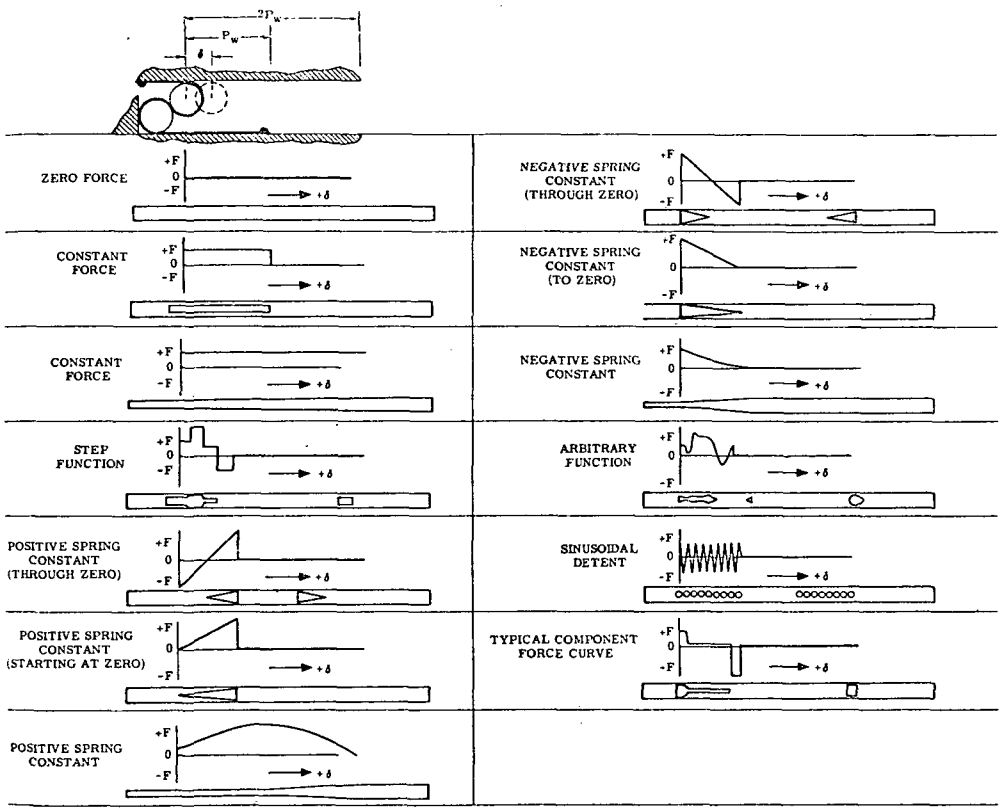


Figure 3. Some Force-Deflection Traces Which Can Be Obtained with Cutout or Tapered Bands

If you want to do some other things with the rolamites, you can generate, by going outside the rolling radius, trochoidal behavior; if you go inside it you generate another kind of behavior which is sort of a watered-down cycloid. By holding one of the rollers stationary and looking at a point on the guide surface you will trace out, by definition, an involute, just like we use in involute profile gearing. If we hold one of the rollers stationary and mark a point on the rolling surface with the other roller it will trace out an epicycloid, and if you permit yourself to go inside the rolling radius on the second roller it will trace out cardioids and all kinds of things; there is just practically no limit to the kind of planar curves that you can generate with this geometry.

ACCOMPLISHING USEFUL DEVICE FUNCTIONS WITH ROLAMITE

## APPLICATION CHARACTERISTICS--ROLLERS

Among other characteristics which make rolamite uniquely fitted for a range of applications, note the instantaneous center. You will notice that, at any time, you can consider a roller as pivoting about its outer tangent point, either the bottom roller or the top roller. It then becomes a simple lever and you can think about it for small motions acting just as a lever pivoting about its outer tangent point.

As for reciprocity--any force that is applied at one roller looks as if it was being applied at the other roller. You can measure the same forces one place or the other, and you have two sources, then, that you can get at all the time. Another important thing is the differential behavior of the rolamite, one of the more fantastic things that the rolamite does.

Next, I would like to show you something you can do to change the inertial characteristics. In this case, I think we have an inertial behavior that is about 1/80th of what it should be for the mass of the objects. Now consider a small roller working with a large one. The small roller is fastened to a large flywheel, and you will notice how sluggishly it accelerates. If you are going to build a device and use this, by the time you put a little energy into this thing, you get a horrendous amount of energy stored in this flywheel. So how do you keep the band from breaking? Well, it's very easy in the rolamite, if there is a little detent notch in the upper guide surface. In that case the roller decouples when it reaches the detent.

## APPLICATION CHARACTERISTICS--BAND

Now let's just briefly talk about some of the other things a band can do, for example, with short tongues. If we use a band with a short tongue and feed that through between the rollers, we have the basis of providing logic and locking, because the roller will pass over the tongue in one direction, but if we let that tongue come out, now it erects itself and will not go back through. So you see we have it latched and it will not return. There are all kinds of logic and electrical contacting, latching, and other things that can be done with these short tongues. Another possible function is potentiometric. Figure 5 shows how, if you put a resistive pattern down on the band, the roller becomes the perfect contactor, and by wiping down over a segment that has a shape you can profile a resistance chain. Next we have an unusual application based on viscoelastic properties. If you take two layers of band material and put a viscoelastic layer between them, something like double sticky Scotch tape between the two bands, you get a damper that can replace a hydraulic shock absorber or provide viscous delay; it gives you a very true viscous restraint. Also, you can program it by changing the width of the viscoelastic layer; you can program the viscous restraint to anything you want with displacement, and you can provide spring forces at the same time by cutouts in the outer bands.

## CONCLUSIONS

I view rolamite fundamentally as a mechanical design technology, one that emanates from a definitely superior suspension system in the first place. It is superior because it has lower friction, lower energy loss; it can do a better job of constraining things to behave the way you want them to, and it is more adaptable. It is appropriate to consider rolamites in virtually anything that has moving parts. Usually the result is a simpler, more foolproof device; this, of course, depends upon the acumen of the one who is doing the design work. But, in general, you come up with a very good result, if you do it well, and if you are not misapplying the principles. It is



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appropriate for anything below, I would say, large earth-moving equipment. I do not believe there is anything in rolamite that speaks to caterpillar tractor treads or anything like this. From things below that size of equipment it speaks very well; there is practically no lower bound at all. We have built rolamite devices with eight thousandths diameter rollers, and they worked very well. Actually, when you are working with the force you can generate relative to the weight of the rollers, you are talking about relatively small devices, just by definition.